An Emotional Response to the Value of Visualization

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DEPARTMENT: Visualization Viewpoints

An Emotional Response to the Value of Visualization

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When assessing the value of visualizations, researchers traditionally focus on efficiency, comprehension, or insight. However, analyzing successful data physicalizations leads to a deep appreciation for hedonic qualities. Informed by the role of emotion in psychology, art, design, marketing, and HCI, we argue for an expanded definition of *value*, applicable to all forms of data visualization.

Data physicalization—the process of creating data representations that can be touched, heard, tasted, and/or seen and that encode data through geometric or material properties--can be traced back to 5500 BC and has been practiced by diverse communities of scholars, artists, learners, and others. Our group of co-authors, representing computer science, cognitive science, psychology, art, and design, gathered at a recent Dagstuhl workshop to learn more about this history and to synthesize ideas from the many disciplines that will shape the future of data physicalization.

Discussing data representations from so many interdisciplinary perspectives led us to a new view, not just of data physicalization specifically, but also of the broader field of visualization. In particular, consider the role of human emotion in understanding, conveying, exploring, and otherwise engaging with data. While we do not propose that digital visualizations preclude emotional responses, physicalizations are often designed to bring human emotion to the forefront. Cognitive science tells us that emotion and physical touch can be tied directly to motivations, actions, and learning. As we learned more, we found it impossible to have a serious conversation about data physicalization without returning multiple times to the role of human emotion. Such an explicit consideration of emotion is in sharp contrast to practice in the broader visualization research community, where the emotional experience is rarely considered in the literature in-tended to establish and codify the value of visualization (van Wijk 2005, Ekete et al. 2012, Stasko 2014, Wall et al. 2019).

Figure 1. Top: Orbacles[1], a public art data physicalization, conveys the impact changing climate will have on bird species in Minnesota. Bottom: A web visualization with identical spatial and color mappings is, likely, a more efficient and accurate way to read the data, but surely not the most impactful. Which has more value? Daniel F. Keefe and MINN_LAB 2017, Photo credit: Chris Savage.

Although details vary, the dominant theme in current theories on the value of visualizations is efficient representation of data. To this, we respond: If emotional qualities have no value, and, based on efficiency, if the value of a visualization actually decreases when we spend more time looking at it, what does this say about the compelling data physicalizations created by the artists featured in this article or collected on the dataphys.org[2] website? If we were to evaluate physicalizations using existing metrics, like ICE-T (Wall et al. 2019), we would completely miss the value of representing data in 30-ft. steel architectural sculptures as compared to a webpage (Figure 1). Certainly, speed of analysis is one marker of value, but are the artifacts created by artists

[1] http://minnlab.squarespace.com/orbacles/
[2] http://dataphys.org/list

working with data less valuable than generic web-based visualizations of the same data? How do we place a value on data representations that engage people on a physical and emotional level?

The central thesis of this paper is that a deep look at what makes data physicalizations successful reveals an important role for emotion, and that by using physicalization as an example, we can develop more appropriate models for the value all forms of visualization can provide. Adopting such a holistic approach could enable the community to address new uses for visualization and open itself to new practitioners and researchers from diverse backgrounds. Indeed, codifying the "value of visualization" in narrow terms can exclude such participation by devaluing works that have obvious merit.

DATA PHYSICALIZATION: EXAMPLES & EXPERIENCES

There is a depth of prior work in physicalization. Here, we highlight several examples and describe their impact on experience. We may not yet know how to codify value in these physicalizations, but clearly physicalizations have a role to play in data communication that is different from digital visualization, yet still important.

The History of Data Physicalization

Data physicalization has a long history, if one considers e.g. Mesopotamian clay tokens (5500 BC) and voting with pebbles in ancient Greece. In the 19th Century, various physical models were developed in the sciences and for engineering purposes, including, for example, a large 3D model of paper slices showing day-by-day electricity consumption for the year 1935 created by the Detroit Edison Company, Stedman's 3D Periodic Table in the 1940s, and physical models of proteins in 1957. Even with the advent of digital visualizations and the increasing power of modern graphics cards and monitors, people have not stopped to build data physicalizations as can be seen by the many recent examples on dataphys.org. This continued use to communicate and express data physically provides further evidence of the importance of touch and emotion to conveying data.

Consider the current trend of crafting with data. Schwab (2019) described how yarn-based visualizations of climate data by scientists, activists, and educators have become popular, not only to foster awareness, but also as an emotional outlet. Joan Sheldon, a marine scientist who brought her crocheted scarf to a conference is quoted: "Even scientists who were familiar with the data wanted to touch the scarf, to find the year they were born...They never would (do this) with a science graph...It approaches you in a different way."

Figure 2. Grewingk Glacier. Adrien Segal, 2015.

Figure 2 shows changes in the natural landscape, occurring over a timespan imperceptible to humans, encoded in a sculpture. The sculpture represents the terminus shape of Grewingk Glacier in Alaska, and its recession over 150 years at an average of 92 feet (~28m) per year. Beginning with the 1850's, the data source was compiled from historical observation, aerial photographs, and satellite imagery that documented its shifting perimeter position over time.

Represented as cast ice, the sculpture retains the temporal nature of the glacier. A record exists in a variety of media. A short time-lapse video shows the sculpture melting from sunrise to mid-day. Audiences often gasp when the ice collapses and begins to disappear. When the physical ice sculpture has been shown in a gallery context, viewers express a desire to touch it to feel the cold. These visceral responses indicate a deep level of emotional engagement with the information contained in the sculpture and a feeling of personal connection to changes that are occurring in the natural landscape, beyond that which is understood from seeing a two dimensional map of glacial retreat (Segal 2019).

Figure 3. Chemo Singing Bowl. Stephen Barrass, 2014.

Data physicalization in the form of a sound-emitting object is called Acoustic Sonification (Barrass 2014). The physical form of the Chemo Singing Bowl (Figure 3), an artifact 3D printed in stainless steel, was created as a gift of thanks to a patient's mother for her care during chemotherapy. The variation in the splines around the bowl is shaped by blood pressure readings recorded over a year of chemotherapy treatment. When the bowl is struck or stroked with a mallet, its sound reflects the data used to shape it. However, the irregularity of the dataset caused the bowl to not sing harmonically. Upon hearing this, the patient responded "that’s exactly how I felt at the time".

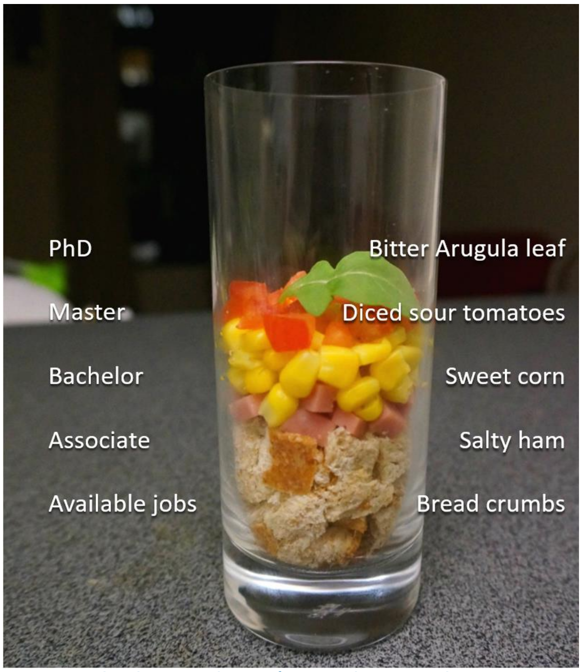

Figure 4. A salad cup to encode the number of annual STEM degree earners and STEM job openings. Yun Wang et al., 2016.

Data edibilization (Wang et al. 2016) leverages edible materials sensed by multiple perceptual channels to convey data stories. When compared with printed visualizations of the same datasets, edibilizations were found attractive, affective, sensorially and intangibly rich, memorable, and sociable. Figure 4 shows an edibilization in the form of salad, encoding annual STEM degree earners. The ingredients are stacked, with bread crumbs corresponding to available jobs, salty ham representing associate degree holders, sweet corns denoting bachelors, diced sour tomatoes referring to masters, and bitter arugula symbolizing PhD graduates. This example engaged viewers, aroused emotions, and deepened their understanding. One participant expressed, “I was puzzled about how the ingredients were chosen for the different (STEM) degrees. When I took a bite of the (arugula) leaf – the representation of Ph.D. – and tasted the bitterness, I said to myself, this is why.” Another mentioned: “eating my (edibilized) academic record means that I have accepted, understood, and digested the results. I have turned the past into nutrition for the future, and now I can let it go.”

EMOTION: A KEY TO THE VALUE OF PHYSICALIZATIONS

What value do physicalizations, like the ones above, provide that we are currently missing in our conception of the value of visualization more broadly? To begin to answer this question, we turn to expertise from a variety of disciplines.

The HCI Perspective

As computers have entered domestic spaces, the field of Human-Computer Interaction (HCI) has evolved from focusing on effectiveness and efficiency towards ‘user experience’ (UX). Concepts such as joy of use, aesthetics and hedonic qualities of interaction have become more important. The field has realized that experience is key when designing technology for personal purposes (e.g. entertainment, social engagement, health tracking or even prayer). This shift is reflected in the professional make-up of the field; since the 2000s, a strong influx of designers has led to a new research focus on ‘interaction design’.

Instead of the functional, reliable, usable, and even the convenient, *user experience* focuses on individual preferences, perceptions, emotions, and motivations. It can concern the acquisition of knowledge and skills or the communication of personal identity. It also covers anticipated use and reflection on past use of a technology. In user experience, aesthetics, humor, surprise, stimulation, even unpredictability and mysteriousness, become design goals.

Within HCI, the subfield of Tangible and Embodied Interaction (TEI) emphasizes the physicality of user interfaces. While tangible interfaces are not necessarily better for learning and user performance (evidence is mixed), they certainly rate higher on user experience (e.g., more pleasurable and meaningful). Objects and materials, textures, colors and forms that already have a rich set of connotations.

Hassenzahl (2010) posits that personal meaning can only be achieved when designers ask the WHY questions, not just WHAT and HOW. We need to know WHY users are motivated to engage/explore (e.g., a need for relatedness), as well as WHAT functionality should be implemented and HOW the user should be able to interact with the data. Fulfillment or frustration of needs leads to positive or negative emotions. Hassenzahl further highlights the role of hedonic aspects in UX, which includes emotional and aesthetic reactions. Wright and McCarthy (2004) argue that emotion is often connected with the sensual (sensory engagement) thread of experience and point out that emotional qualities of experience are part of sense-making, and thus an integral part of our process of understanding. Given visualization’s goal of sense-making, this provides a strong argument for the importance of emotion.

The Role of Emotion for Engaging Museum Visitors

Museums and other scenarios of ‘casual learning’ are a typical setting for presenting information to the public. Museums are aware of the role of emotion for enhancing engagement, and museum visitors are seen as active interpreters. Such self-directed information-seeking activities are described as ‘free-choice learning’, in contrast to school-based learning. Learners are motivated in these environments by: curiosity; experience-seeking; recharging and contemplative experiences; challenges; playful experiences; beauty; introspective and imaginative experiences; and attractors, with some people being attracted to ideas and others relating to objects or people (i.e., empathizing with stories about individuals) or thriving on sensorial engagement. Physicalizations lend themselves to use in museums as they can communicate ideas and make data accessible while providing enticing objects and evoking sensory experience.

Perry (2012) distinguishes four types of engagement with exhibits: physical, intellectual, social, and emotional. Emotional engagement includes being touched by beauty, surprise, wonder, excitement, hope, but also sadness, fear or anger. Modern museums not only hope to convey knowledge or trigger interest and awareness but also often want visitors to develop empathy and think about values, given that exhibitions may address anything from scientific discovery to Civil Rights struggles. Heritage scholars also argue that visitor experience may include becoming emotional, uncomfortable or upset, and identifying with the “voices” of an exhibition. Museum design might thus aim to raise awareness of challenging, yet important issues by engendering emotional experiences - for visitors to become engaged with the issue, to remember, and to change minds and future actions.

How Physicalization Affects Sensation, Perception, and Cognition

A core advantage of physicalization is to make the structure of 3D displays visually accessible. In contrast to 2D representations, physicalization creates true 3D structures that can be viewed from multiple perspectives through the observer’s free movement, potentially engaging all their senses, from stereo vision to touch, smell and even taste (Fig. 4). Continuous sensorimotor feedback is integrated with ongoing visual input – with minimal cognitive load.

Physicalized media enhance perceptual processes in multiple senses. The size of a physical work is directly scaled in relation to the observer. Visual cues to material are enhanced; objects emit smells and sounds. Physically touching an object, along with exploratory movements (haptics, or active touch), reveals a panoply of features, including surface properties like roughness, internal properties like compliance and stiffness, and structural properties like shape and distribution of mass (Lederman & Klatzky 1987). Touch is essential - these properties do not emerge from vision alone. Memory for the experience of touching an object endures for days, even when no test of recollection was expected.

Beyond added information, touch creates emotional connection. People like touching. Smooth rounded shapes that fit the hand, materials with naps like velvet or fur, or surfaces with complex textures seem to invite touch. The invitation is so compelling that museums must post guards. More generally, people show a desire to touch objects, whether purely for exploration or for their anticipated pleasurable effects. Individuals' tendencies have been assessed via the Need-for-Touch psychometric scale (Peck & Childers 2003). Once people are induced to touch, there are consequences. Marketing experts found that when people touch a product as well as look at it, the result is an increase in personal valuation, sense of ownership, and ultimately, likelihood of purchase.

Some connections from touch to emotion are mediated by direct neural pathways. A subset of nerves under hairy skin, constituting a system called emotional touch, are routed directly to brain parts associated with body regulation and affective response to sensation. People show positive effects of socially supportive touch across the life span. Analysis of the emotional consequences of touching materials (Guest et al. 2010) suggest underlying dimensions of comfort, arousal, and sensuality. Material substances can be differentiated along these dimensions: rough fabrics are arousing and relatively low in comfort. The emotional response depends to some extent on the method and body site of contact. In general, active touch produces less intense emotions than passively receiving touch, possibly because the experience of being touched mimics social interaction.

Art and Design

Art and design strategically employ formal and compositional arrangements within a medium to achieve certain behavioral effects in the audience. Seeley (2012) proposes that works of art aim "to trigger perceptual, affective, and cognitive responses diagnostic for their content in viewers, spectators, listeners, and readers." The success of art and design is often evaluated by the degree to which the audience can connect and engage with it. McDonagh (2015) places equal emphasis on the goals of design "for both the functional (e.g. assisting with a task) and the emotional needs of the user."

An important feature of data physicalization is that the object or artifact is embedded with information that is being communicated to the audience through art and design. The skilled application of the medium into a physical form means that the information is sensed not just by the remoteness of vision but is simultaneously accessible to the mind through the body. Representing information in the realm of the physical thus increases accessibility of the embedded information to the user and enhances the ability to have an engaging experience by enhancing perceptual, affective, and cognitive responses. Seeley (2012) directly ties understanding and appreciation of art to its information content, that is, how audiences "acquire, represent, manipulate, and use information embedded in the formal structure of artworks."

REVISING THE WAY WE VALUE VISUALIZATIONS

Prior Models

Several researchers have attempted to capture the "value" of visualizations while focusing on their analytic and knowledge-generating value in combination with cost factors such as effectiveness and efficiency, exemplified by van Wijk (2005). Fekete et al. (2008) argue that communicating the value of information visualizations (InfoVis) is extremely difficult. The authors of these works focus largely on commonly cited goals and values, such as amplification of cognition and related core activities: exploratory analysis, insight formation, or hypothesis generation.

Models and methods for describing and determining the value of visualizations tend to follow this tradition of a transactional view that centers on the efficiency and accuracy of extracting information. Stasko (2014) proposed an equation, to characterize the value (V) of visualizations: $V = T + I + E + C$. This includes the factors of time (T) needed to answer questions, ability for insight (I) formation, ability to communicate the essence (E) or a general understanding of the data, and building of confidence (C) and trust in the data.

Wall et al. extended this work by proposing the "ICE-T" model and a methodology for assessing the value of visualizations using heuristic methods (Wall et al., 2019, http://visvalue.org/). These past models have (purposefully) avoided talking about hedonic qualities of visualizations and their importance to other factors of value. In addition, none explicitly mention that other related factors such as social and affective engagement could be a value in its own right.

Prior Work on Emotion in Visualization

While analytic value is still the most established value metric in the visualization research community, others begin to offer different interpretations; together with an emerging recognition by visualization researchers that humans are emotional, not just analytical, beings.

Sprague and Tory (2012) explored how and why people use visualizations in casual contexts and uncovered a number of motivations for using visualizations other than efficiency and accuracy of information extraction. For example, people used visualizations to avoid boredom, be entertained, or simply out of curiosity. The work by Borkin et al. (2013,2016) argues for memorability of visualizations as a value metric that has implications for other cognitive processes, such as understanding. Others have proposed domain-specific value metrics, such as for the digital humanities (Hinrichs et al., 2018): aesthetic provocation, supporting a speculative process, and mediating discourse. The importance and value of aesthetics in visualization (Moere & Purchase 2011) has similarly been recognized for emotional and personal responses.

A specific example relating to emotion and data encodings involves our understanding of the role of color. Until quite recently, the visualization literature was pragmatic in advising that color should be used to maximize the saliency of data variables and is sometimes quite strident in its critique of color "misuse". In contrast, Bartram et al. (2017), used a data mining approach to develop color palettes that evoke a mood or meaning other than pure data quantity or typology.

At the fringes of formal research, the role of data-inspired artworks has been appreciated, for example, through the Art Program associated with the IEEE VIS conference (http://visap.net/program#exhibition). However, the separation of these works from the core scientific (VAST, InfoVis, and SciVis) program arguably shows that the community is unsure of how to frame or incorporate this influence. Conversely, there are artwork-inspired visualizations; for example, renderings of weather data in the style of impressionist paintings tended to be not only functional but well-liked (Kozik et al. 2018).

Another relatively recent, though well-publicized area that seeks to address this need is Data Storytelling (Riche et al. 2018). Inspired by the growing use of data visualization in popular media, this research seeks to inform through popular engagement. Particularly emotive digital examples include presentations of the Fallen of WW2[3], and an analysis of mass shootings through "anthopomorphic unit visualization" wherein the data points are represented by humanoid figures (Ivanov, et al. 2018).

An Expanded Model

While current frameworks on the value of data visualization are valuable, they do not capture the role of emotion in decision making. We propose an expanded model, which incorporates prior models and reflects our proposal that user engagement with data representations goes beyond cognitive processes:

[3] http://www.fallen.io/ww2/

V = C + E (A, P, I, S), where the value of a data representation derives from:

C – its creativity. In terms of introducing new and original ideas

E – its ability to engage beyond the raw information content, with respect to distinctions of Perry (2012) through

A – Affective (emotional) engagement

P – Physical interaction being invited through touch and movement, real or imagined

I – Intellectual engagement

S –Social engagement

Affective engagement with a data representation can be characterized as a continuous stream of valence judgments (good-bad - analogously to Hassenzahl 2010). Beyond this level, emotional experience can be deep and rich, arousing feelings of awe, respect, wonder, as well as amusement, concern, fear, disgust, anger, or intimidation.

Physical engagement invites people to spend time touching and interacting with the data (even if just in imagination), moving around it to take different perspectives, bending down to read a label, employing senses including smell and hearing.

Intellectual engagement is the ability to engage the viewer in intellectual activities such as recognition, analysis, and contemplation. Stasko's and van Wijk's models focus on efficiency measures such as the amount of knowledge extracted, number of insights gained, comprehensiveness of overviews (essence) understood, confidence in the results, and overall analysis time. Our model allows for further components of intellectual engagement, where the duration of analysis, for example, may be of little or no importance. Identifying an expanded set of components should be the subject of in-depth future research.

Social engagement is seen when observers talk with companions, but also when laughing, gesturing, and mimicking the body postures of others.

Engagement factors may act independently of one another. For example, there might be a feeling of awe when the glacier finally collapses and a lively social exchange, but without intellectual comprehension of what it stands for. This does not negate the physicalization's value, which in our view goes beyond comprehensibility. While still in need of elaboration, we see our model as expressing the prerequisites of the prior models, but also offering new values. We call on designers of data presentation to rethink the design for engagement in its many forms – which could ultimately benefit all forms of visualization.

CONCLUSION

Historical precedents and emerging research on data physicalization highlight the need for a more holistic approach to defining the success or "value" of visualizations, especially as they relate to human emotion. We call upon the visualization community to expand our definition for the value of visualization, by including the factors that are so powerfully evident when considering physicalizations. We provide an initial proposal for an expanded model that brings emotion to the forefront.

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